Transient Overvoltages in Secondary Systems

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Significance:
Part 3 – Recorded occurrences

This unclassified (available to anyone) report was prepared to provide more details (until then, contained in classified internal reports or summarized in the two IEEE papers reprinted in this Part 3) on the measurements made at General Electric during the 1963-1967 period.

Only brief remarks are made in this report on possible suppression methods. Papers included in Part 6 (Tutorials), Part 7 (Mitigation techniques) and Part 8 (Coordination of cascaded SPDs) provide information on protection techniques prior to and after the emergence and widespread use of metal-oxide varistors.

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SUMMARY

Transient overvoltages have been recorded in secondary systems for a period of four years, using recording oscilloscopes and surge counters.

Conclusive evidence has been accumulated on the occurrence of surges at potentially damaging levels on 120 volts residential circuits. Less frequent and less severe surges were found on commercial and industrial circuits.

This report is a summary of measurements made from 1963-1967 and has been adapted from a 1967 internal report. An up-to-date bibliography is included.

KEY WORDS

surge

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TRANSIENT OVERVOLTAGES IN SECONDARY SYSTEMS

F. D. Martzloff

I. INTRODUCTION

The increasing use of semiconductors in consumer and commercial applications has increased the risk of component failures due to transient overvoltages. This situation was recognized by the General Electric Company in the early sixties, and a program was initiated in 1962 for the purpose, among others, of recording transient overvoltages in low voltage systems in order to obtain factual information for an estimate of this risk.

Transients were recorded with oscilloscopes at a number of locations, in order to obtain data on representative waveshapes. These data were supplemented by a second project in which a large number of locations were monitored, using a fixed threshold surge counter especially developed for this program.

This report combines a presentation of the new results with a review of earlier data, in order to summarize present knowledge on the occurrence of transient overvoltages in secondary systems, with references to related areas of effects on semiconductors and transient suppression.

The cause of transients, the recording and the results are discussed, and conclusions based on statistical considerations are presented.

II. CONCLUSIONS

1. (a) Two major causes of transient overvoltages exist in residential secondary circuits: surges generated within the house by some device such as relays, contactors, mercury switches, etc., and surges fed in from the power service entrance, primarily lightning-induced.

(b) Commercial or industrial secondary systems are not subjected to the internally generated surges found in residential circuits, as they are "stiffer" than the latter.

2. Internally generated surges above 1200 volts are likely to occur at frequent intervals (one or more per day) in about 2.5% of all U.S. households.

3. Lightning-induced surges may occur at a rate of 0.1 to 0.9 per household and per year. Statistical evidence in this case is not as firm as in the case of the internally generated surges.

4. These surges can definitely cause failures in unprotected appliances, especially those containing semiconductors directly exposed to the line voltage.

5. A number of commercially available devices offer various amounts of protection at various costs. The need for built-in protection versus no protection, or protection external to the appliance at the owner's expense is a subject of

discussion rather than a hard fact, since it involves variable parameters such as nuisance costs, prestige, duration of warranties, etc., in addition to the simple probability of failure considerations.

6. In spite of the impossibility of making definitive and all-encompassing conclusions, the author hopes that this report will increase the awareness of the occurrence of potentially damaging surge voltages on residential secondary circuits and promote a better anticipation of associated problems, which should ultimately increase the reliability of electronic products.

III. TRANSIENT MEASUREMENTS IN SECONDARY CIRCUITS

The measurement of transients was conducted over a period of three years; in 1962 and 1963 with oscilloscopes and in 1965 with surge counters designed and built in 1964. The objective of the oscilloscope measurements was to explore the characteristics (waveshape, magnitude) of surges, while the objective of the surge counter measurements was to establish a broad base for the statistical treatment of the results.

1. Oscilloscope Measurements

Table I shows an analysis of the surges recorded in terms of most severe, most frequent, and average number per hour at each of 23 locations.

Briefly, the oscilloscopes are modified Tektronix 515 oscilloscopes where a nonpolarized sweep trigger is provided by the transient overvoltage occurring in the circuit being monitored. A 35 mm camera, with no shutter, continuously monitors the blanked-out screen until a surge triggers the logarithmic sweep, at which time the transient is displayed on the screen and recorded on the film, and the motor-driven camera advances one frame.

This equipment, not without electronic and mechanical incidents, provided the means to monitor the voltage in homes and commercial buildings for a period of several days and thus establish patterns for transients recurring within this time period.

Typical waveshapes (corresponding to severe cases for <u>amplitude</u> but typical as far as <u>shape</u> is concerned) are shown in the oscillograms of Figs. 1, 2, and 3.

These oscilloscope measurements indicated that potentially damaging surges can occur very frequently in some households, while other households were relatively free from frequent disturbances. In some cases, the occurrence of frequent surges was correlated with the operation of an appliance such as a furnace, refrigerator, etc.

Measurements in larger secondary systems, i.e., commercial or industrial buildings, did not record frequent, internally generated surges similar to those found in households. Lower amplitude, less frequent occurrences were found, believed to be associated with switching surges or lightning-induced surges involving the complete local power grid.

2. Recordings with Surge Counters

The oscilloscope measurements clearly established the dual source of surges in households, internal or external. In order to evaluate the possible effect of these on a national scale, a program of designing and building about 100 surge counters for installation in as many households as possible was initiated in 1964. These were installed late in 1964, and the readings monitored and analysed in 1965.

2.1 Test Plan

The recording of household surges was divided into two separate periods, each with distinct objectives. A first recording period held in winter and early spring covered short periods at each of a large number of residences, in order to investigate the proportion of households subjected to frequent internally generated surges.

A second recording period held in late spring and summer was organized at a reduced number of locations with longer periods, in order to investigate the frequency of lightning-induced surges at a number of specific locations.

A related program was also carried on at two locations where frequent internally generated surges were occurring, to demonstrate the effectiveness of the suppression obtainable from a small Thyrector stack connected at the outlets.

The surge counter design has been described in a previously published paper.(1) It provides cumulative counting of surges in excess of 1200 V or 2000 V for durations above 0.2 μs when plugged into the 120 V outlet. *

Briefly, these recorders consist of a solenoid driven counter, with a storage capacitor discharged into the solenoid when triggered by a surge in excess of a set threshold, of one polarity. The threshold level of the counter was set at 1200 volts for three quarters and at 2000 volts for one quarter of the counters. The storage capacitor was held charged by a high resistance rectifier power supply drawing power from the line being monitored.

The choice of the 1200 volts and 2000 volts threshold levels was the result of data on the performance of semiconductors, especially diodes and SCR's under transient inverse voltage. It seems that appliance circuits containing diodes or SCR's connected either directly or by low impedance components to the incoming 120 volt line may fail when the surges on this line exceed 1200 volts. On the other hand, a device with some degree of filtering, such as an input transformer, may require in the order of 2000 volts on the incoming line to pass on 1200 volts to the semiconductor(s) in the circuit.

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*These recorders were designed specifically for installation in 120 V outlets and have a relatively low input impedance. Therefore, they may load down a circuit if, for instance, installed on the load side of a switch.

2. 2 Internally Generated Surges Investigation

This investigation was carried on with the cooperation of individual engineers at 18 departments, who installed the counters in their homes and returned the records to the author for compilation.

The recording period lasted from December 1964 to March 1965, corresponding to an expected minimum of lightning activity, and involved about 250 homes. Complete results are shown in Table II.

The results are summarized as follows:

1. Six homes in a total of 250 homes are subjected to repetitive surges in the 1200 to 2000 volt range, which are most likely limited to each of the six, i. e., not affecting adjacent houses. This represents a percentage of 2. 4% of the houses surveyed where potentially damaging repetitive surges can occur. The statistical validity of this percentage is discussed below.

2. Three isolated random surges were recorded, associated with no known or suspected system disturbances.

The recording results were analyzed by G. J. Hahn, who prepared the following discussion.

Statistical Aspects of the Recording Results

The data indicated 6 voltage surge situations in a total of 250 homes sampled. This indicates a rate of 2. 4% in the sample. One would expect that the true voltage surge rate in the population from which the random sample was taken would differ from the sample rate due to statistical variations. However, one may be 99% confident that the voltage surge rate in the population is between 0. 6% and 6. 3% and 95% confident that the true proportion is between 0. 9% and 5. 3%.

Assuming now that more homes had been surveyed, one can wonder how much narrower the band would be. In response to this question, if we had observed 12 voltage surges in 500 homes, the 99% confidence interval would have been 1. 0% to 4. 8% and the 95% interval would have been 1. 2% to 4. 2%. Similarly, with 24 voltage surges in a sample of 1000 the 99% confidence interval would have been 1. 3% to 4. 0% and the 95% confidence interval would have been 1. 5% to 3. 6%.

The above results refer to statistical variations only, and thus represent limits on the proportion of voltage surges in the population from which the sample was selected. Thus, they do not take into account any possible biases that might have been introduced by such factors as restrictions in selecting members of the sample (principally GE engineers in a number of designated locations) or the time of year (winter months).

The statistical calculations are based on the well-known method of establishing confidence intervals for the binomial parameter using the Poisson approximation. Further details may be found in statistical tests.[2, 3, 4]

Discussion of the Results

Within the limitation that the homes surveyed are assumed to be typical of all residential buildings where new solid state appliances are likely to be found, the 1% to 5% probability of repetitive surges is not negligible. That is, electronic appliances with a surge damage threshold below 1200 volts are likely to suffer in-warranty failures at a rate of 1% to 5% of sales.

While the small number (6) of locations detected in this survey may appear to be small and thus intuitively unconvincing, there is a 99% level of confidence that the actual rate is 0. 6 to 6%. *

Continuing the data accumulation by increasing the number of homes surveyed will of course increase the validity of the conclusions, but not by a very large amount; for instance, if the same percentage (2. 4%) had been obtained from a sample of 1000 homes (an effort 4 times as large as the one reported here) the range of probability for a 99% confidence level would be reduced to 1. 3 to 4% compared to the present 0. 6 to 6%. This offers some incentive for increasing the number of homes surveyed, especially at locations where only a few homes were surveyed, but again, the return of better data are disproportionate to the effort that could be applied in one year.

2. 3 Externally Generated Surges

2. 3. 1 Test Procedure

At the conclusion of the repetitive surge detection program the surge counters were installed for an extended period at a few homes for the duration of the summer, or at least for several weeks. Presumably, these homes were not subjected to repetitive internally generated surges (as confirmed by the recordings), so that only externally generated surges would be recorded. Except when a correlation was established with a lightning storm, there is no available information on the cause of the surge, so that lightning as well as system switching surges are included in this statistic.

Table III summarized the recording data. A complete discussion of the results by G. J. Hahn follows.

2. 3. 2 Analysis of Voltage Surge Data and Some Implications

A. Introduction

Data have been obtained on single polarity voltage surges above 1200 volts on 39 counters installed in a total of 91 homes in 15 localities for a total exposure time of 841 weeks. A total of 8 occurrences were observed during this

*The fact that the counters record only one polarity is immaterial in this case: the point was to detect those houses which had repetitive surges, not the number of surges at each location. (With random polarity in the surges, and some damping in oscillating surges, there is a factor of more than one and less than two to be applied to the number of surges indicated in order to obtain the total number of surges of both polarities.)

period. From this information, it is desired to draw some conclusions concerning the expected number of such surges per home per year. The total time per counter ranged from 9 weeks to 48 weeks, with the average time per device being 22 weeks. The program was so planned that all devices would be in homes during the summer months, that is, the period during which lightning storms, and thus voltage surges, are most likely to occur.

B. Results of Analysis

Analyses were conducted based on the following two alternate assumptions:

1. Voltage surges above 1200 volts occur only during the period of year that the counters were installed in the homes. Thus, although the counters were in homes only for parts of the year, the time involved was so chosen (namely, the summer months) that no further surges would have been noted even if each counter had been run for 52 consecutive weeks.

2. Voltage surges occur completely randomly throughout the year. Thus a counter that was in use only 9 weeks would on the average have only a third as many observed surges as a counter in use for a period of 27 weeks.

The above two assumptions clearly represent extremes. Thus, although neither is very realistic, results based on such assumptions permit one to obtain bounds within which one can reasonably expect the true expected number of surges to lie. The results are as follows:

Under assumption 1: A total of 8 surges occurred on 39 counters, thus the best estimate of the expected number of surges per home per year is 8/39 or 0.205. This estimate is subject to statistical error, since only a limited number of counters were involved. However, from the appropriate statistical calculations[3, 4] we can state with 90% confidence that the average number of surges is between 0.102 per year and 0.370 per year.

Under assumption 2: A total of 8 surges were observed in a total of 16.173 years of testing. Thus the expected number of surges per year is 8/16.173 or 0.495. The 90% confidence interval on this estimate is 0.246 surges per year to 0.892 surges per year.

The above calculations refer only to single polarity surges. If one is interested in all surges, the given values need be multiplied by a value corresponding to the additional proportion of opposite polarity surges above 1200 volts, which do <u>not</u> also result in positive surges above 1200 volts. This multiplying factor is probably in the order of 1.6, accounting for the damping between the first and second 1/2 cycle of an oscillating surge.

Some additional assumptions are also involved in the analysis. Although these assumptions are not strictly met, they are probably not sufficiently incorrect to critically affect the validity of the analysis. These assumptions are:

1. The homes were selected strictly at random.
2. The voltage surge rate is the same from one home to the next.
3. All voltage surges of one polarity during the period of installation were recorded.

If it is desired to relate the above data to probability of appliance failure, one must clearly multiply the given values by the probability that a surge above 1200 volts would lead to appliance failure assuming the appliance is in use during the time of the lightning storm. (This would clearly be different for a toaster from what it would be for a radio.) If one is interested only in failures during the warranty period an additional adjustment would be required.

C. Possible Further Analysis

A more refined analysis is possible by taking into account the geographical location of the homes, the occurrence rate of the lightning storms during the period under examination in these homes, and the exact dates at which the voltage surges occurred in order to obtain a measure of the probability of a voltage surge per lightning storm. The resulting values can then be used in conjunction with the information given in Ref. 4 to calculate a probability of voltage surge in any specified geographic area during a particular part of the year. Such an analysis would remove the need for making one of the two alternate assumptions stated above and lead to a single set of estimates. However, this would require more detailed data than could be collected in this program.

2.4 Surge Suppression Experiment

At two of the locations where repetitive surges were found, a prototype surge suppressor was installed at the receptacle into which the counter was plugged. This suppressor consists of a Thyrector packaged for plug-in installation at receptacles, and is currently under evaluation by the Semiconductor Products Department for the home market. The counters were installed in alternating periods with and without suppressors, and the recording rates compared. A counter was especially modified to record surges over 600 volts in order to roughly evaluate the effectiveness of the suppressor in reducing the surges of 1200 volts or more occurring without suppression.

Location No. 1 - (Home in Ft. Wayne, Ind., refrigerator identified as source)

Dates (1965)	Conditions	Days	No. of Surges Above 1200 Volts Recorded	No. of Surges Above 600 Volts Recorded
3/11 to 8/10	No Suppressor	152	252	Unknown
8/10 to 9/16	Suppressor	37	0	Unknown
9/16 to 11/12	No Suppressor	57	107	Unknown
10/29 to 11/12	No Suppressor	14	Unknown	11
11/12 to 11/26	Suppressor	14	0	0
(1966)				
1/24 to 1/31	No Suppressor	7	Unknown	3
1/31 to 2/8	No Suppressor	7	Unknown	12

Location No. 2 - (Home in Newton, Mass., oil burner identified as source)

Dates (1966)	Conditions	Days	No. of Surges Above 600 Volts Recorded
5/10 to 5/17	No Suppressor	7	8
5/17 to 5/24	Suppressor in	7	0
5/24 to 5/31	No Suppressor	7	0

There were eight recordings which occurred in the first seven days without the use of the suppressor. On or about May 18, the warm weather really set in, and it is doubtful that the burner went on after that, which explains the absence of surges in the second period without the suppressor.

The results of the experiment at both locations are quite conclusive for the effectiveness of the Thyrector in suppressing the internally generated surges from a potentially damaging value in excess of 1200 volts to an innocuous value of less than 600 volts.

IV. DISCUSSION OF THE TRANSIENT MEASUREMENTS

1. Distribution of Magnitudes

The histogram, Fig. 4, shows the distribution as recorded by the oscilloscopes; the low frequency shown below 500 volts is due to a deliberate cut-off in the sensitivity of the oscilloscopes (in order to limit the number of oscilloscope triggers). This is to be compared with the distribution reported in Ref. 5 and reproduced on Fig. 5, where the frequency increased by three decades with a threshold lowered from 400 to 50 volts.

The highest internally generated surge was about 2800 volts, with the majority of the surges in the 1000 to 1500 volts range at locations where these were occurring frequently.

Lightning surges were found as high as 5.6 kV; however, the small total number of surges recorded makes it difficult to present definitive conclusions.

2. Distribution of Surge Generating Appliances

The 2.4% estimate derived from the surge counter survey has already been discussed from the statistical point of view in Section III. The real problem, however, is that of trading off minimum manufacturing cost (and, therefore, a calculated risk of failure) against complaint expenses. This is certainly the prerogative and responsibility of individual departments, and not that of the author. However, it is hoped that the data presented here will contribute a factual input to this trade-off.

V. EFFECTS OF TRANSIENT OVERVOLTAGES ON SEMICONDUCTORS

Previous investigations have indicated some significant factors to be considered when semiconductors are exposed to transient voltages in the reverse direction (forward direction generally results at worst in one-half cycle forward conduction into the load, which is not catastrophic with the AC power sources):

1. Failure modes, nonavalanche rectifiers

   a. The nonavalanche (or at least the non-"controlled avalanche") rectifiers fail by breakdown of the insulation surface at the edges of the wafer. This breakdown is a characteristic of the semiconductor geometry and materials, and has no direct relation to the PRV rating of the device.

   b. Application of a reverse voltage transient during forward conduction produces failure at levels substantially lower than when the transient is applied during blocking.

   c. No significant difference was found between the failure level for single vs multiple (several thousands) application of overvoltages.

   d. For steep pulse fronts (shorter than 1 μs), the failure level increases with rate of rise.

   e. Aging of semiconductors by storage at high temperature does not affect the failure levels.

   f. Energy level of the transient, i.e., duration for a specified voltage appearing across a specified impedance, does not affect the failure level.

2. Failure Modes--Controlled Avalanche Rectifiers

   The energy dissipating characteristic of the device can hold the transient voltage level below surface breakdown level, however, long pulses may heat the material so much as to produce:

   - bulk failures by hot spot
   - an increase in the voltage across the device such that surface breakdown voltage is reached

   Therefore, care and not indiscriminate selection is required in applying avalanche characteristics for circuits exposed to "long" transients.

VI. SUPPRESSION METHODS

Transient suppression can be accomplished either at the source or at the sensitive load. System designers may be able to specify the suppression at the source, but the majority of users will have to protect their appliances at the load, or at some location of their system. For instance, in a home, the suppressor may be installed at the service entrance or at an outlet. The service entrance location is optimum for protection against incoming surges, while the outlet location is optimum for protection of a single appliance at that outlet. Nevertheless, a substantial protection is obtained throughout the house if a suppressor is installed at one outlet only.

While protective devices are fairly well known, their application can lead to some pitfalls.[6] For large and expensive equipment, it seems more acceptable to provide some investment in surge protection, which can then be specified by technical performance rather than cost. On the other hand, mass market devices are subject to economic criteria which make the selection of a surge protector a more delicate trade-off.

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VIII. ACKNOWLEDGMENTS

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The contribution of G.J. Hahn, Statistician, Research and Development Center, in interpreting and discussing the statistical aspects of the results is acknowledged.

TABLE I

DETAILED ANALYSIS OF RECORDED SURGES

	LOCATION	MOST SEVERE SURGE				MOST FREQUENT SURGE				AVERAGE NUMBER OF SURGES PER HOUR	DURATION OF OBSERVATION HOURS	REMARKS
		*TYPE	CREST VOLTS	PK-TO-PK VOLTS	DURATION μs OR CYCLES	*TYPE	CREST VOLTS	PK-TO-PK VOLTS	DURATION μs OR CYCLES			
	D.P. Shattuck	A-1.5	700	1400	10 μs	A-1.5	300	600	10 μs	0.07	450	
	K.N. Mathes	A-2.0	750	1440	20 μs	A-2.0	500	1000	20 μs	0.14	250	Fluorescent light switching
	P. Chowdhuri	B-0.5	600	1000	1 cycle	B-0.5	300	500	1 cycle	0.05	500	
	P.H. Bosworth	B-0.5	400	750	2 cycles	B-0.5	300	500	2 cycles	0.2	300	
	R.L. Maul	C	640	-	5 μs	Two few surges to show typical value.				10 surges total	500	
1962	R.G. Hoft	B-0.3	400	600	1 cycle	B-0.3	250	400	1 cycle	0.01	300	
	P.A. Fessler	B-1	1800	3400	1 cycle	B-1.0	800	1400	1 cycle	0.03	1000	Probably all during lightning storm.
	Ellis Hospital	C	1200	-	10 μs	B-0.5	300	600	4 cycles	0.1	900	
	St. Clare's Hospital	C	2700	-	9 μs	C	900	-	5 μs	0.1	1000	All during lightning storm.
	Barney's Dept. Store	B-0.3	1100	1400	1 cycle	Two few surges to show typical value.				4 surges total	700	
	L & M Motel	B-0.5	300	500	1 cycle	B-0.5	300	500	1 cycle	0.5	600	
	H.R. Sellers	B-0.25	1500	2000	4 μs 1 cycle	same as most severe				0.2	100	Probably oil burner.
	W.H. Bellamy	B-0.25	2500	3500	4 μs 1 cycle	B-0.25	2000	3000	4 μs 1 cycle	0.4	125	oil burner
	W.J. Smiley	B-0.2	1500	2000	5 μs 1 cycle	same as most severe				0.15	150	Probably water pump
	J.R. Ross	B-0.2	1700	2000	5 μs 1 cycle	B-0.2	1400	1700	5 μs 1 cycle	0.06	500	oil burner
	F.D. Martzloff	B-0.1	350	400	5 μs 1 cycle	too few to show typical				4 surges total	150	House adjacent to J.R. Ross
1963	P.A. Abetti	C	800	-	15 μs	-	-	-	-	1 surge total	200	Probably lightning
	D.G. Gruber	B-0.25	800	1000	12 μs 3 cycles	B-0.25	600	800	12 μs 3 cycles	0.05	1500	Rural area
	K.H. Hoffmann	B-0.15	400	600	15 μs	B-0.13	200	350	30 μs	0.4	130	includes low amplitude surges
	Deer Park	B-0.5	5600	10000	2 μs 4 cycles	B-0.3	1000	1500	3 μs 1 cycle	0.1	400	Lightning stroke within 1000 feet.
	Palmetto	B-0.2	1400	200	10 μs 4 cycles	B-0.2	600	1000	10 μs 4 cycles	0.07	100	Lightning
	#2 MG System	C	600	-	50 μs	C	300	-	50 μs	0.15	150	isolated system
	480 volt feed system	B-1.2	300	400	.4 μs ½ cycle	too few to show typical				0.1	100	

No surges above 300 volts were recorded at the 7 following locations: GE Bldg. 37, roof-top house, air conditioning bus, 440 volts bus, 550 volts bus; Hotel Van Curler; MG system #1; B. Murphy.

*TYPE: A - Long Oscillation; B - Damped Oscillation; C - Unidirectional - NUMBER SHOWS FREQUENCY IN MEGACYCLES

TABLE II

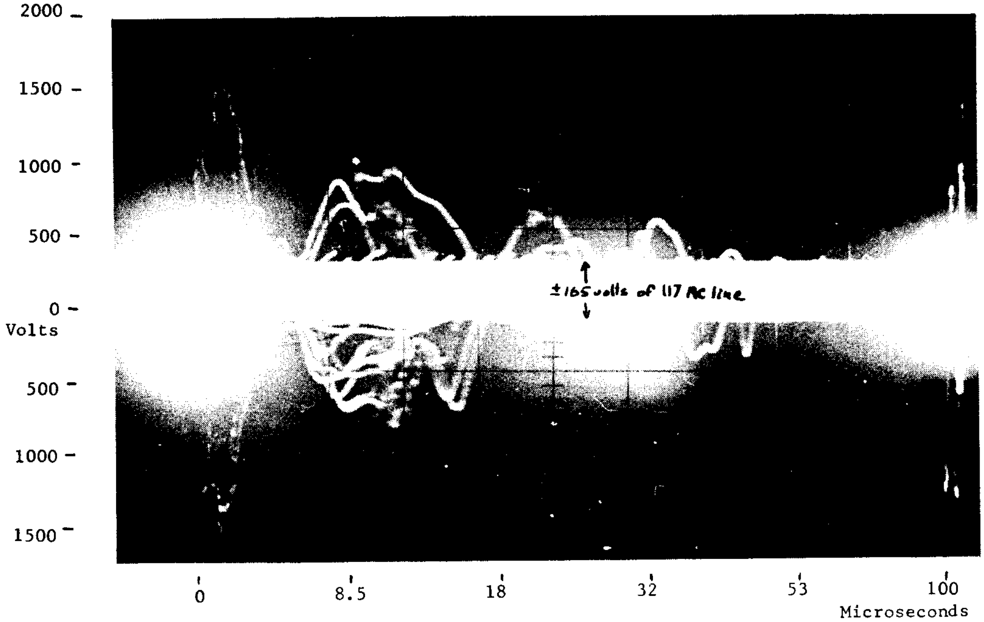
SUMMARY OF SURGE COUNTER RECORDINGS IN HOMES - DECEMBER 1964 to MARCH 1965

Location (Approximate)	Number of homes surveyed	Recording Period (weeks)	Number of Houses with Surge Activity	Detailed Information
Providence, R.I.	4	2-6	None	
Cleveland, Ohio				
Lg. Lamp data	14	2-4	1	1 surge over 1200 - community-wide power failure.
Min. Lamp data	14	2-4	None	
Auburn, N.Y.	12	2-3	None	
Lynchburg, Va.	3	2-3	None	
Syracuse, N.Y.	8	1-2	1	1200 to 2000V surge, 1 polarity only, 64 counts in 10 days, probably refrigerator.
Chicago, Ill.	23	1-6	None	
Ashland, Mass.	24	1-2	2	1 surge over 1200V in a 20 day period, no known system disturbance. 6 surges over 1200V in a 12 day period, no known system disturbance.
Holland, Mich.	6	2-10	None	
Louisville, Ky.	10	2-6	1	1 surge over 1200V - lightning stroke which burned out TV set and UHF converter in the home.
Somersworth, N.H. (and nearby N.H. & Maine locations)	50	1-2	1	Surges between 1200 and 2000 volts, some probably close to 1200 as two counters at same location had difference in count. Counter simultaneously installed in adjacent house did not record any surges. Most frequent count at night in cold weather; probable cause is oil burner.
Plainville, Conn.	5	10	None	DAD & CPDD data.
Asheboro, N.C.	24	1-2	None	
Ft. Wayne, Ind.				
Spty. Transf. data	23	1-2	None	
Laboratory data	15	2-4	3	Location #1*: (7 counts) Ballast side of switch controlling a fluorescent lamp, no surges on the line side. Location #2*: (5 counts) Surges recorded in connection with operation of GE portable mixer. Location #3*: (5 counts) Surges recorded as fan motor plug is removed from same outlet as counter. * All between 1200 and 2000V
DeKalb, Ill.	10 4	3 12	None	
Pittsfield	26	1-2	1	One surge with no known system disturbance

TABLE III

Summary of Surge Counter Recordings in Homes
April - December 1965

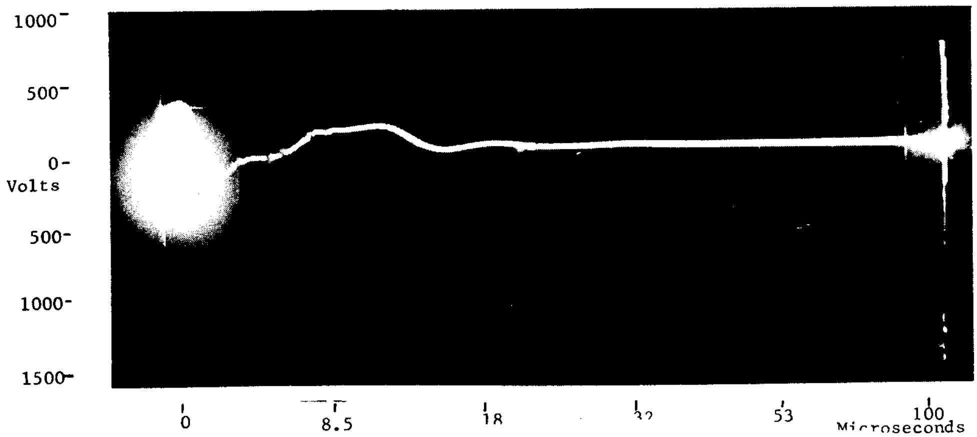
Location	No. of Homes	Total Home x Week	No. Surges Over 1200 V	Remarks
Providence, R.I.	6	60	1 in 1 Home	Frequent power interruption at home where surge was recorded.
Ashboro, N.C.	13	85	0	Several storms in area.
De Kalb, Ill.	11	60	1 in Home #1 1 in Home #2	Violent storm. No known disturbance.
Somersworth, N.H.	3	48	1 in 1 Home	Owner installed arrester after the first count.
Chicago, Ill.	12	58	0	
Cleveland, Ohio	5	66	1 in 1 Home	During power outage.
Decatur, Ill.	12	72	1 in Home #1 2 in Home #3	During storm. During same storm.
Cleveland, Ohio	3	40	0	
Holland, Mich.	7	56	0	
Auburn, N.Y.	3	70	0	
Springfield, Pa.	1	24	0	
Ashland, Mass.	6	72	0	
Pittsfield, Mass	3	60	1 in 1 Home	2000 volt counter at same outlet did not register (during storm).
Plainsville, Conn.	3	60	0	
Lynchburg, Va.	3	15	0	
Total	91	846	9 in 8 Homes	



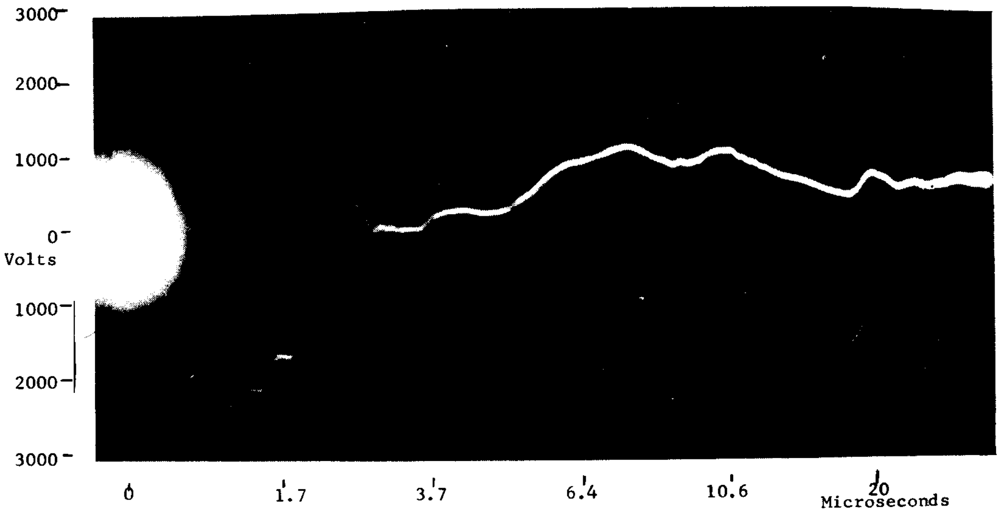
Composite record showing surges for a 24-hour period.

Oscilloscope is triggered for each surge, plus once every hour, resulting in ± 165 volt band of steady-state 60 cps voltage.

Recordings above 1800V are blanked out by oscilloscope.



Single surge occurring 150 μs after initial, low amplitude surge triggered the oscilloscope.



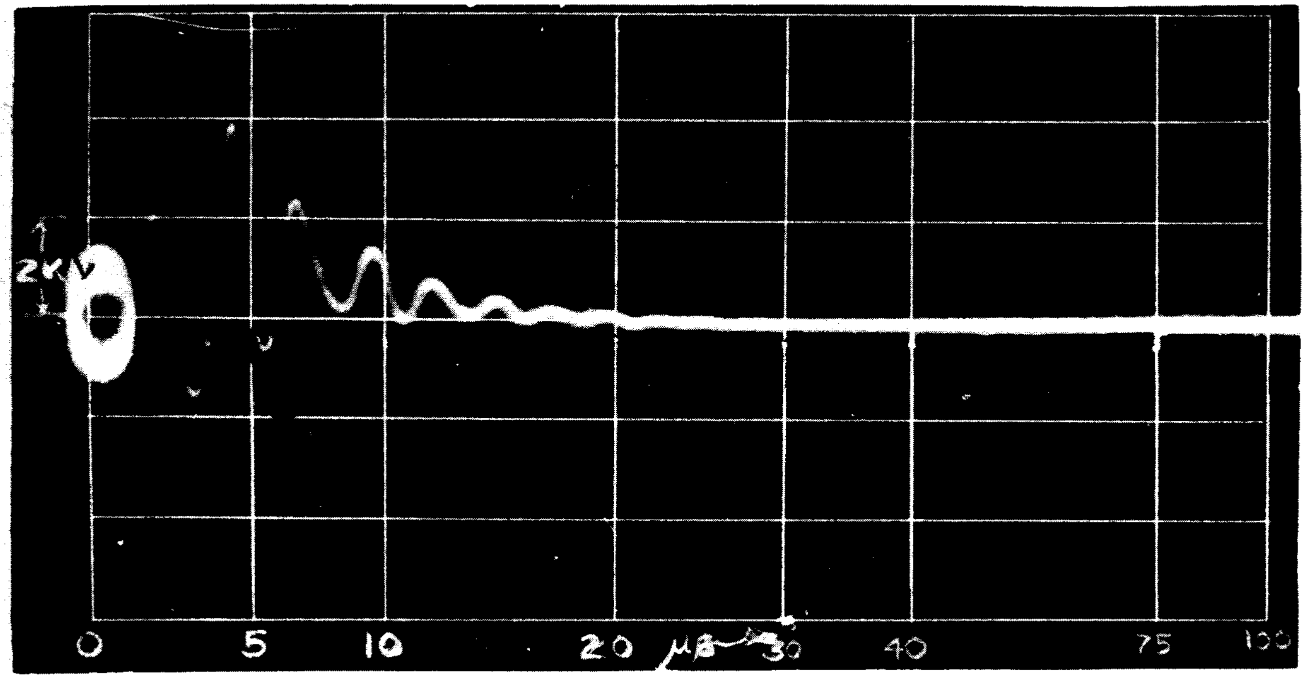
Maximum recorded surge, at 2600 volts.

In a 5-day period surges of this wave shape were recorded as follows:

Number of surges	Voltage Range
1	2500 - 3000
21	2000 - 2500
18	1500 - 2000
13	1000 - 1500

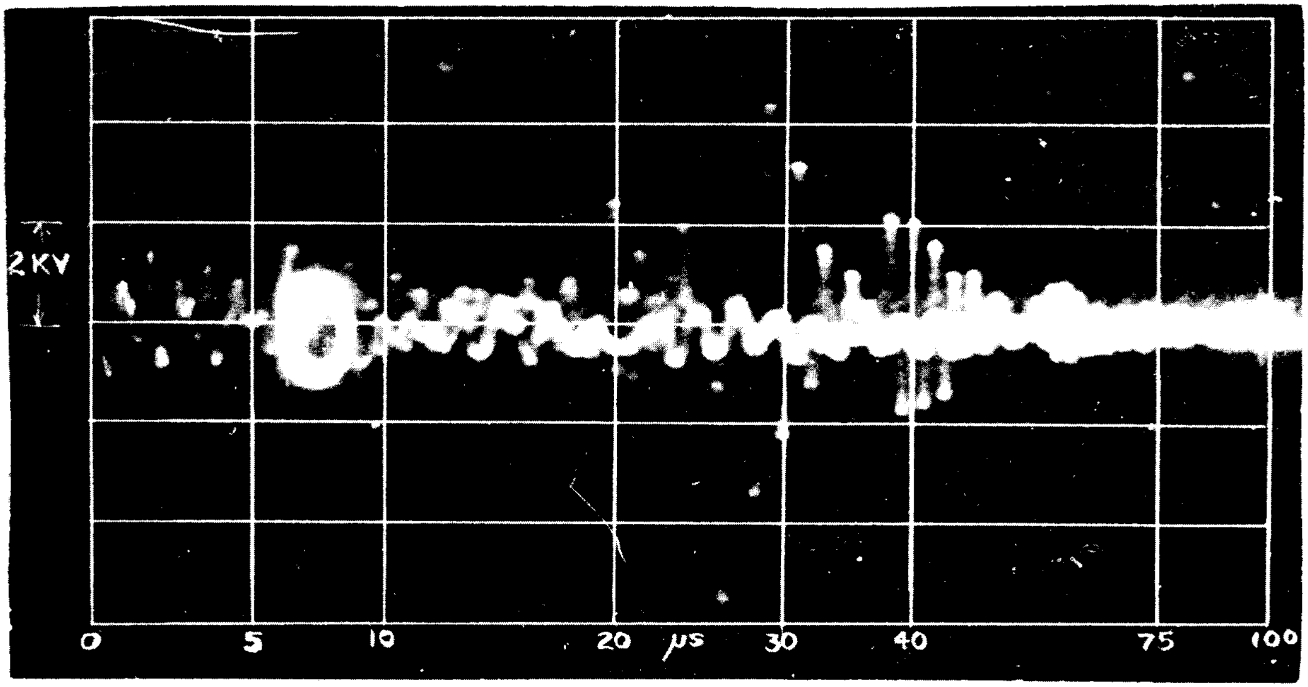
Cause: H.V. transformer for oil furnace interrupted

Fig. 1. Typical Surges Recorded at Stewart Manor, L. I., N. Y., February 16-21, 1963.



Lightning surge at Deer Park

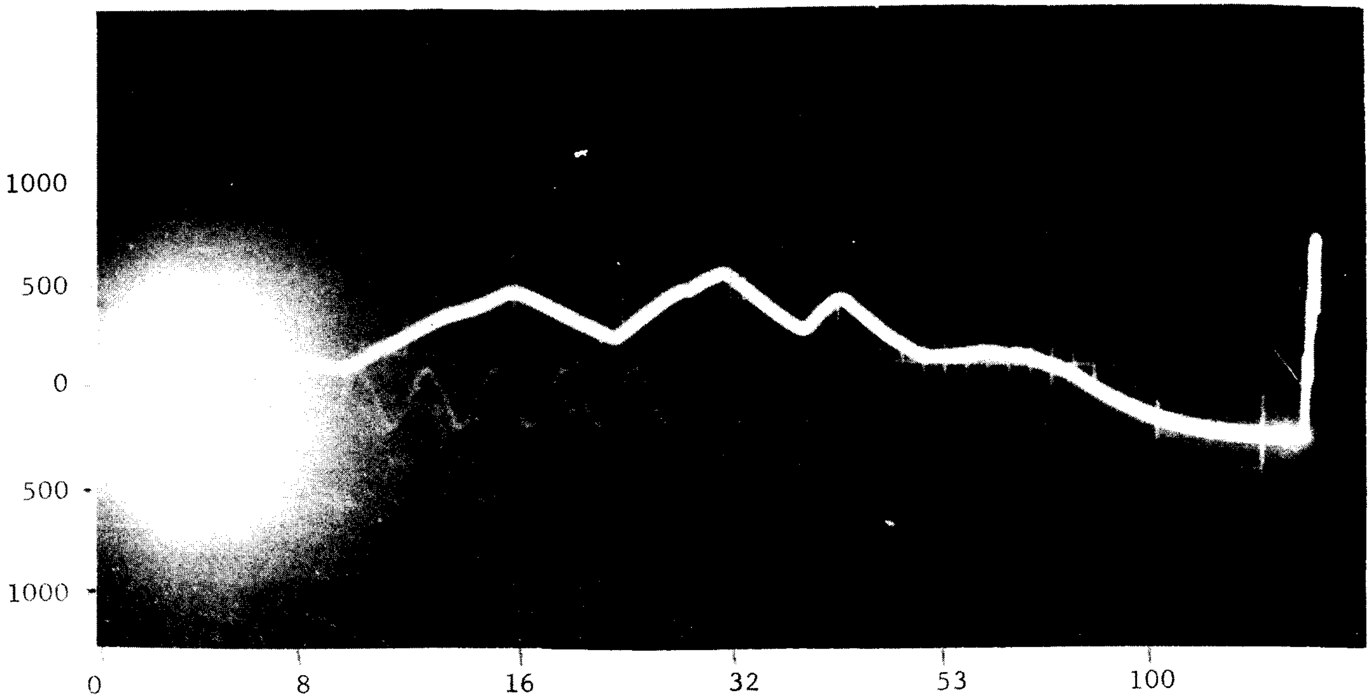
3.8 KV crest, 1μs rise time
330 KC oscillation



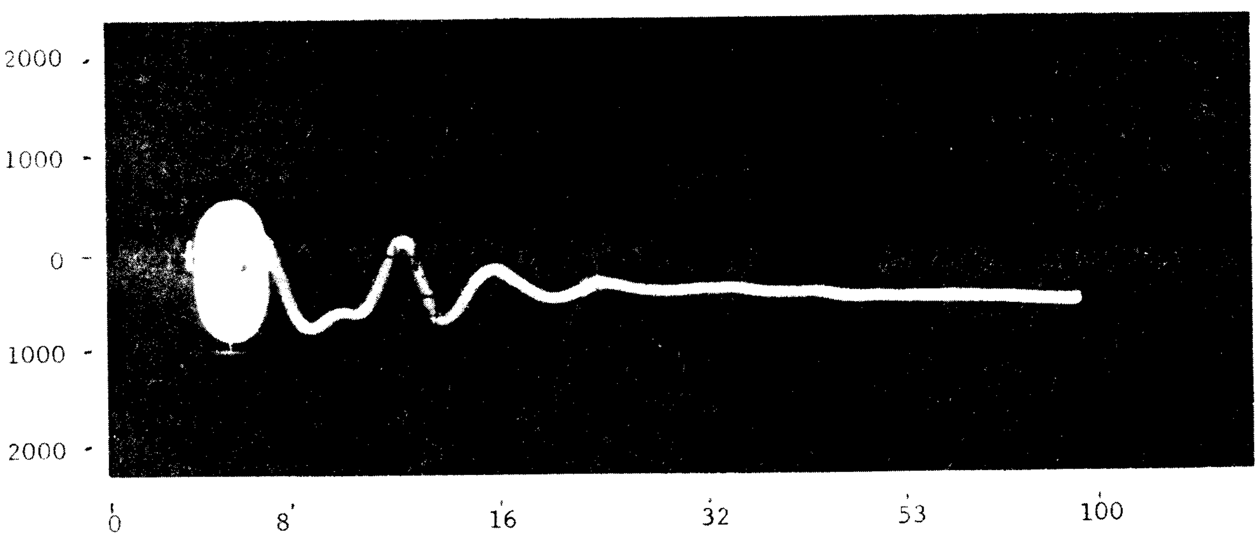
Lightning surge at Deer Park

5.6 KV crest, rise time < 1μs
500 KC oscillation

Fig. 2. Transients Recorded on Overhead Distribution Systems in Charleston, S. C., July 1963.



Switching transient with restrikes--probably external to the house.
(The faint sine wave corresponds to the return of the electron beam which was not completely blanked out. It illustrates the peak-to-peak value of the steady state 117 voltage, but not at the same rate as the forward sweep.)



Internal switching transient
(15 such transients in 1500 hours)

Fig. 3. Transients Recorded at a Farmhouse, August 1963.

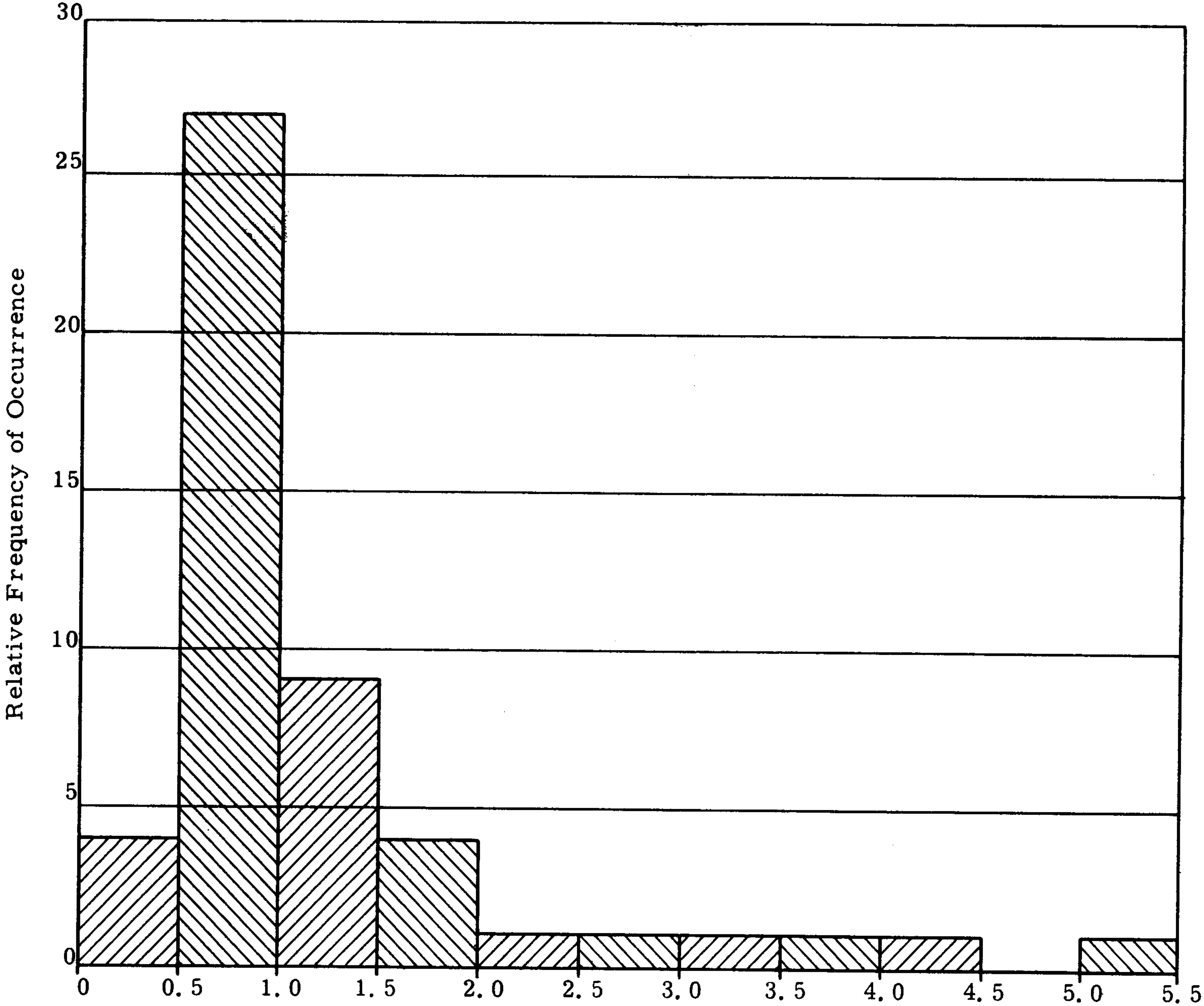

Relative Frequency of Occurrence
30
25
20
15
10
5
0
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
kV

Fig. 4

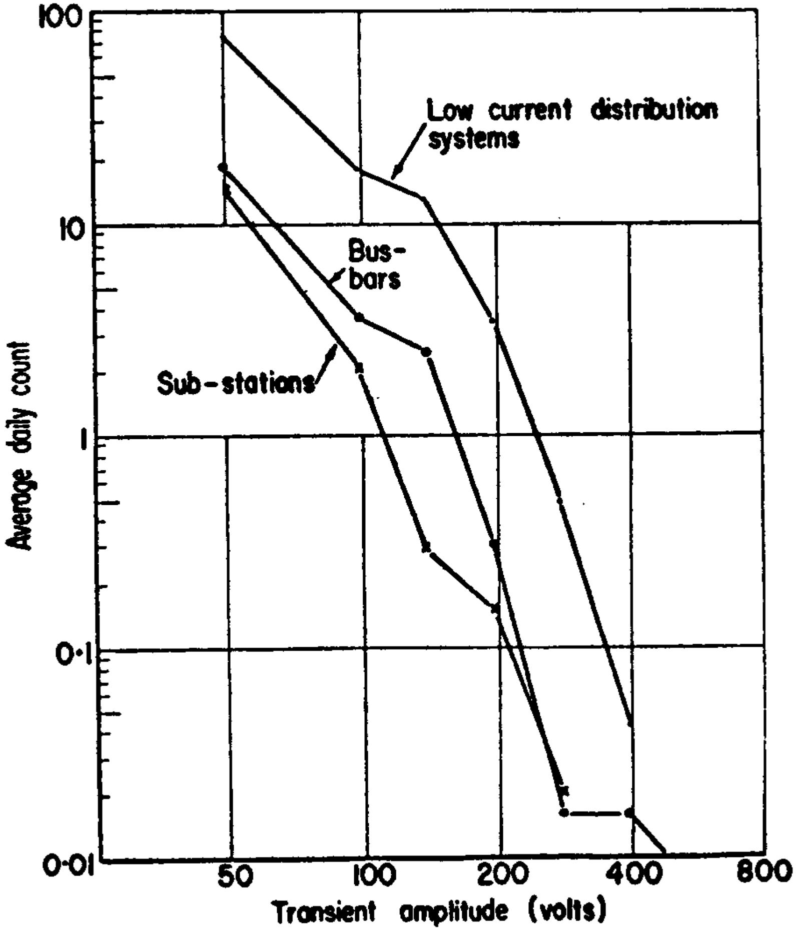


Fig. 5. Variation of frequency of occurrence with amplitude for short duration transients.

Fig. 5. Excerpt from Bull and Nethercot Paper.

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